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The Dual Calsphere Experiment

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ABSTRACT

Two smooth polished 14-in.-diameter aluminum spheres weighing 2.2 lb and 22 lb have been simultaneously injected into nearly identical 600-naut-mi circular polar orbits. These spheres will provide (a) standard radar targets and (b) observations of the relative change in the orbital parameters with time. These objects, designated 1964-63C and 1964-63E, are assigned SPADATS Nos. 900 and 902. From semimajor axis decrement measurements derived from U.S. Navy Space Surveillance System (NAVSPASUR) observations, it has been established that No. 900 is the light sphere and that No. 902 is the heavy sphere.

Since the scattering cross section of these spheres is less than 0.1 sq ft at 108 Mc, they are not adequate for Space Surveillance System calibration at the present time, although they will be seen more often when system frequency is increased to 216 Mc and transmitter power is increased. They are seen often enough at present, however, so that good orbital elements are obtained from the NAVSPASUR observations, and it has been possible to identify the light satellite and the heavy one from the relative change in semimajor axis caused by residual atmospheric drag. A density measurement has been obtained from the decrement of the semimajor axis of the light sphere that agrees to within ten percent with the accepted value for the quiet-sun period.

PROBLEM STATUS

This is an interim report on one phase of the problem; work is continuing on this and other phases.

AUTHORIZATION

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THE DUAL CALSPHERE EXPERIMENT

INTRODUCTION

There has existed since from nearly the beginning of the "space age" a requirement for a standard target for the U.S. Navy Space Surveillance System (1) and other radars and space-surveillance sensors. In order to serve both monostatic and multistatic systems with operating frequencies from uhf to X band, a smooth rigid metal sphere is indicated with a diameter of ten feet or more. The Echo satellites are unsatisfactory for calibration purposes, since they are not smooth spheres, especially at microwave frequency, so that the scattering pattern is far from uniform. Satellites of the Explorer 9 series (POLKA DOT 1961 Delta 1) are unsatisfactory for the same reasons, and also their scattering pattern is complicated by the fact that they consist essentially of two insulated hemispheres (to serve as a tracking-beacon dipole antenna). All balloon-type satellites suffer from the effects of solar-radiation pressure, which causes the orbital parameters to change rapidly with time, making accurate predictions difficult.

In addition to the specifications of the satellite itself, preferred orbital parameters exist for system calibration. In order to check sensor parameters such as antenna gain, effective power output, and signal-level measurement, the satellite should be low enough to yield a high signal-to-noise ratio. On the other hand, to check system probability of detection, the signal-to-noise ratio should be marginal, indicating a high-altitude satellite. Thus a relatively eccentric orbit is indicated, and in order for all sensors to be served, a high inclination is required. There are several satellites in orbit fulfilling these requirements at present, but unfortunately they are not smooth spheres.

The opportunity was presented to NRL by the Bureau of Naval Weapons and their contractor, the Applied Physics Laboratory of Johns Hopkins University, to orbit a secondary payload on a launch from the Pacific Missile Range in October 1964. In order not to jeopardize the primary payload, it was not possible to orbit so large a calibration sphere (Calsphere) as would be desired, and the nominal orbit was not optimum either. Secondary payload weight allowances were quite generous, however, so it was decided to orbit two smaller spheres of 14-in. diameter with different masses. The differing masses (2.2 lb and 22 lb) would allow a number of experiments involving the relative change in orbital parameters (period, primarily) to be performed.

THE SATELLITES

The satellites are identical in size, material, and surface finish. Figure 1 shows a satellite in its mounting bracket. They are mounted outboard from the adapter used to mate the payload with the Able Star second stage. This mounting is shown during a shock-and-vibration test in mockup in Fig. 2. The satellites are spun aluminum spheres, two hemispheres welded along the equator and buffed to a high polish. They are secured to the mounting bracket by a spring-loaded bolt. On separation an explosive bolt cutter in the mounting bracket is fired; the bolt end is withdrawn into the satellite by a spring, leaving only a 3/8-in.-diameter hole to mar the sphere. Another spring in the bracket imparts 1.3 ft/sec separation velocity to the spheres. The spring constants are designed to cause equal separation velocity to the spheres. The heavy sphere is loaded with lead at the pole nearest to the mounting bracket. The desirability of a symmetrical mass distribution could not be justified in view of the additional construction problems

Fig. 1 - Calsphere in launching cradle

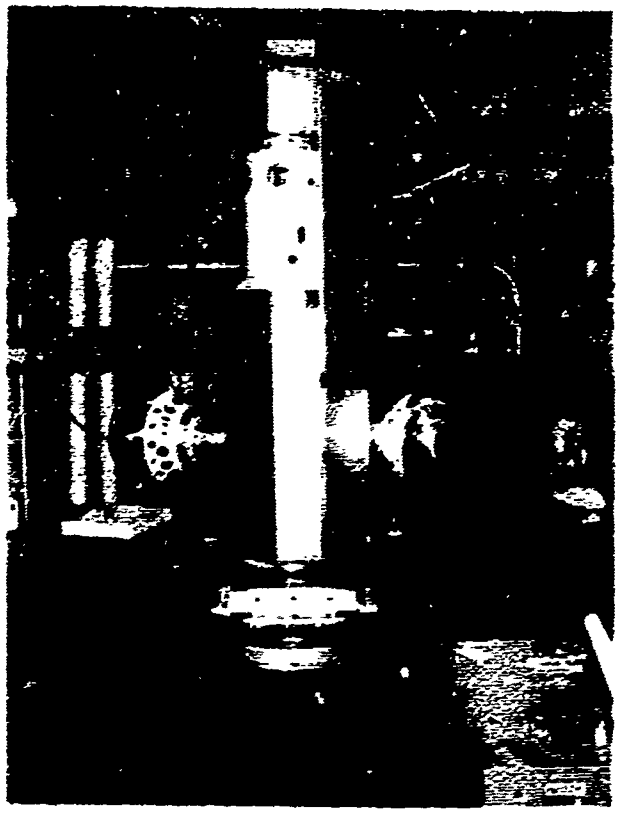

Fig. 2 - Calspheres attached to adapter

resulting from the increased stresses and deflection of the mounting structure. The following list summarizes the physical properties of these satellites.

Mass (lb)	
900	2.16
902	21.6
Diameter (in.)	14.0
Dimensional tolerance (in.)	±1/32
Material thickness, aluminum alloy #5052 - H32 (in.)	1/32
Mounting holes (in.)	
900 one (in.)	3/8
902 two 1/8 in. holes and one (in.)	3/8

THE LAUNCH

The launch occurred on schedule on Oct. 6, 1964, from Pt. Arguello, Pacific Missile Range. On the first pass over the U.S. Navy Space Surveillance System, separation of the primary payload, an adapter structure, and the last-stage rocket was confirmed. The Calspheres themselves were to remain on the adapter for eight minutes after main payload separation, at which time a heater in a subliming switch was to fire the bolt cutters, separating the Calspheres from the adapter. However, no observations on the spheres were obtained until 021810.5Z on Oct. 12, when the Ft. Stewart, Georgia Space Surveillance System observed one sphere 13.3° west of the station. At 161022.2Z on Oct. 13, the second sphere was observed by the Elephant Butte Space Surveillance System 33.3° to the west. Confirmation that these objects were indeed associated with this launch was obtained on 021616.4Z on Oct. 14, when both spheres were seen from the Ft. Stewart and Silver Lake, Mississippi stations, so that height could be measured. The objects have been observed

intermittently since then, and the first orbital elements were issued by the Space Surveillance System on Nov. 15. It is apparent from this chronology that the signals received by the Space Surveillance System were very weak. A record of one of the stronger signals received at Silver Lake is shown in Fig. 3. Enough single-station observations were obtained, however, to plot the time difference in system penetration as compared to the adapter, as shown in Fig. 4. From the curve it is apparent that separation of the spheres from the adapter did not occur until 18 hours after launch, indicating that the heater in the subliming switch did not function, but instead that the material slowly sublimed in the space environment. Vacuum-chamber tests with this material indicate that this is a reasonable period.

From Figs. 5 and 6, a plot of the semimajor axes of these satellites obtained from the Space Surveillance System orbital elements, it was possible to determine that the heavy sphere was SPADAT No. 902 and the light one No. 900 because of the different decrements. A representative set of orbit elements issued by NAVSPASUR is shown in Table 1. It is noted that the orbit is very nearly circular and also very nearly polar, so that these satellites are too high to yield enough signal-to-noise ratio to check system parameters. However, because they are seen by the system relatively rarely, they make ideal targets for determining degradation in system probability of detection.

CALIBRATION TARGET CONSIDERATIONS

The backscattering cross section of a smooth perfectly conducting sphere (Fig. 7) has been calculated theoretically by Lord Rayleigh, Mie, and many others (2). This theory is the basis for the calibration method to be used against microwave monostatic radars. For uhf sensors the spheres are not large enough to be in the optical region, where the scattering cross section is equal to πr^2 and independent of scattering angle, but are in the Mie or resonance region, where both backscatter cross section and scattering pattern are highly dependent upon the frequency. The exact value of the backscattering cross section in this region is still in some doubt (various authorities disagree on the value at the first minimum). The scattering pattern has been computed rigorously (3) by King and Wu for values of $2\pi r/\lambda$ of 1.1 and greater. The backscattering cross section is again accurately known in the Rayleigh region, but the authors have not been able to locate a reference giving the scattering pattern in this region. Some experimental work has been done by the Ohio State University Research Facility (4) for $2\pi r/\lambda$ as small as 0.66 which indicates large departures from circularity of the scattering pattern. Thus, as an aid in calibrating the Space Surveillance System at 108 Mc ($2\pi r/\lambda$ = 0.4) these satellites are poor, since the bistatic angles involved are too large to use the backscatter curve (Fig. 7), and data on the scattering pattern are unavailable. It is expected that this data will be obtained from a small computational effort by the Conductron Corporation and funded by NRL in the near future. All that is known at present is that it is less than indicated in Fig. 7, or less than 0.10 sq ft.

EXPERIMENTAL RESULTS

In addition to the observations made by the Space Surveillance System, orbital elements were furnished Cornell Aeronautical Laboratories in order to direct their high-power (50 kw average, 50 Mw peak) S-band tracking radar at Newstead, New York (5). A two-minute track was obtained on Nov. 24, 1964, on sphere No. 902. The signal-to-noise ratio was too poor for monopulse operation, so open-loop operation from a tape of directing data computed from the orbital elements was used, with manual peaking. They have concluded from these signal levels that a calibration error of 3 to 4 db had existed in their system. At present NAVSPASUR is issuing updated differentially connected orbital elements on the spheres every week or so, using observations from the Space Surveillance System only. Elements are good enough to predict the time of system penetration to within one second, and semimajor axis is computed to eight decimal places, of which probably seven are significant.

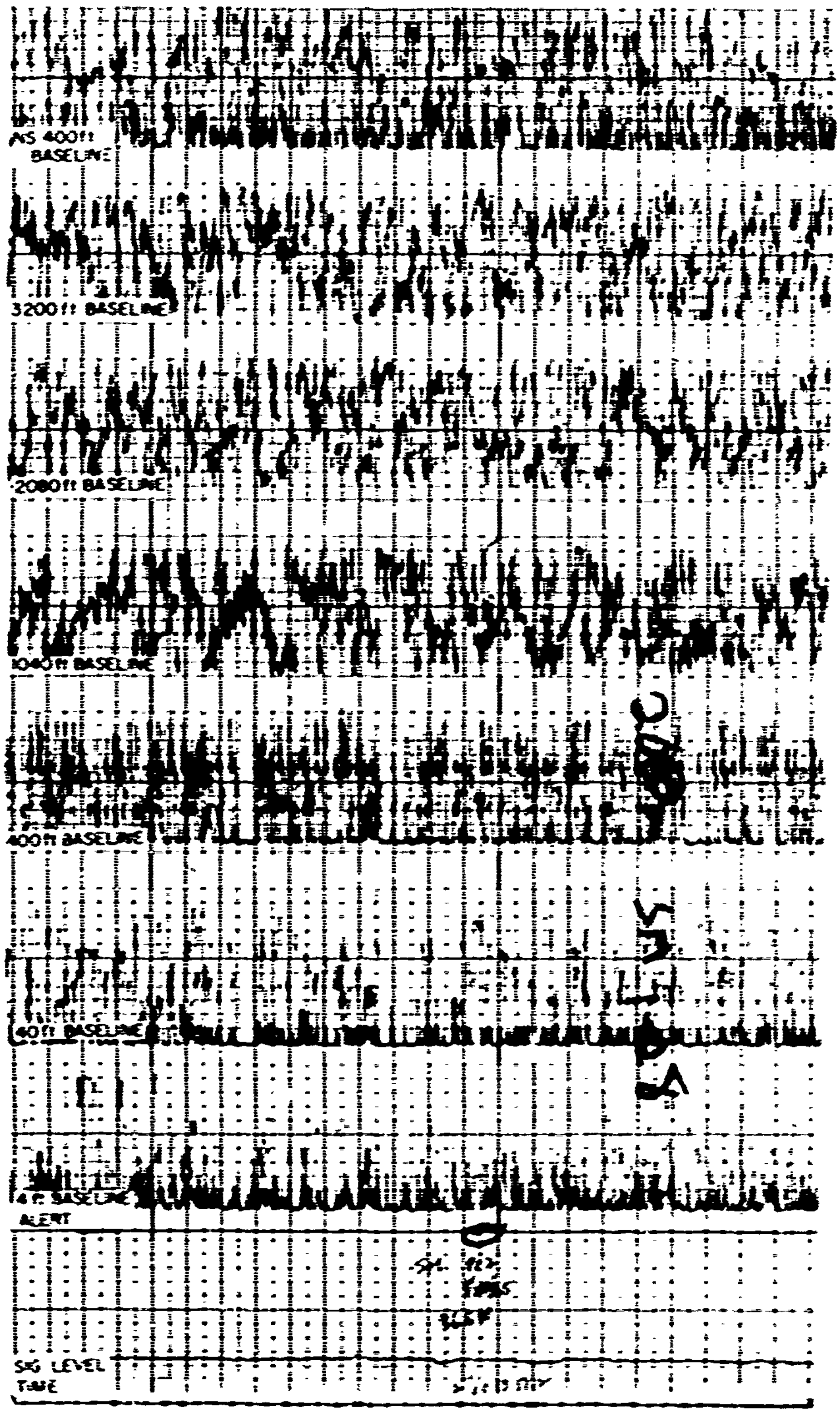

Fig. 3 - Record of U.S. Navy Space Surveillance System for a typical Calsphere pass

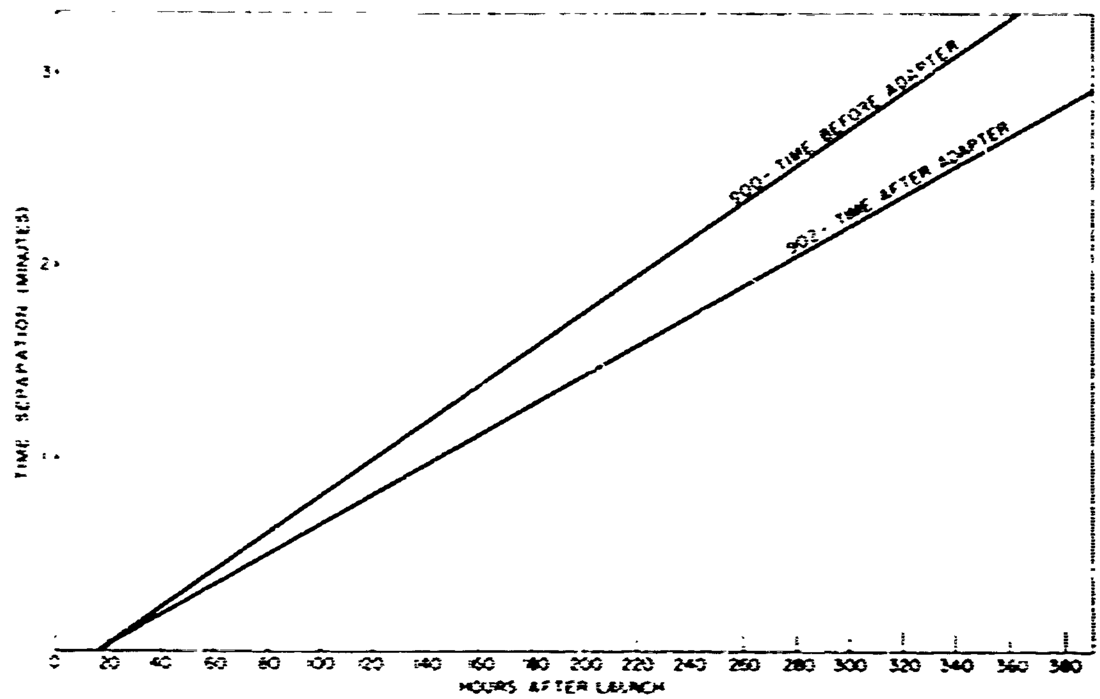

Fig. 4 - Time separation in minutes of light sphere (900) and heavy sphere (902) from adapter (897)

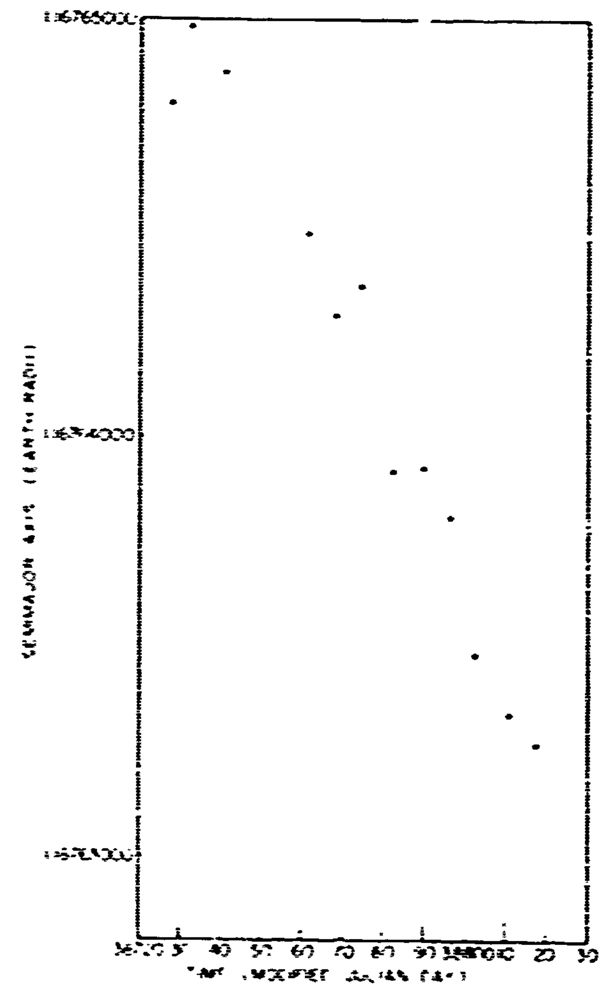

Fig. 5 - Decrease in semimajor axis of light sphere (900) as a function of time

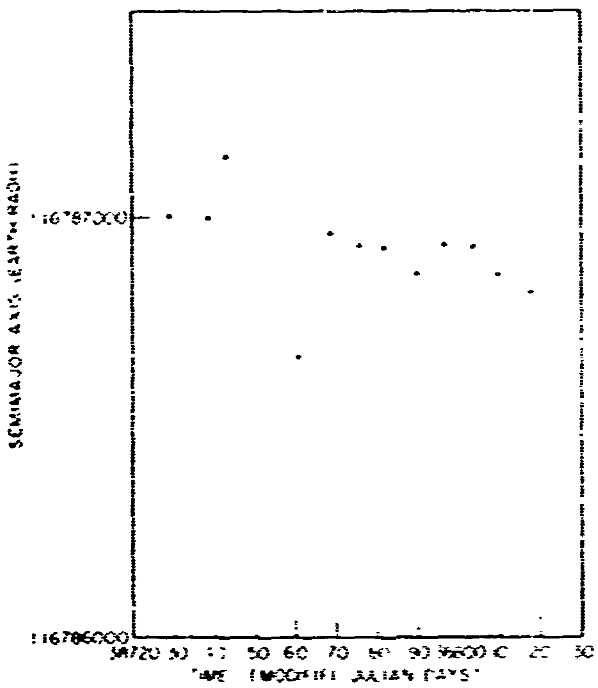

Fig. 6 - Decrease in semimajor axis of heavy sphere (902) as a function of time

Table 1
Orbital Characteristics of the Calspheres

Parameter	Light Sphere	Heavy Sphere
SPADAT number	900	902
Epoch	650220	650219
Period (minutes)	106.5693	106.6016
Inclination (degrees)	89.938	89.900
Perigee ht. (stat. miles)	649.7	650.6
Apogee ht. (stat. miles)	673.5	674.5
Eccentricity	0.00257	0.00258
Mean Anomaly (degrees)	278.383	275.238
Right Ascension (degrees)	330.617	330.603
Argument of Perigee (degrees)	22.540	16.997
Regression of Node (degrees/day)	-0.006	-0.010
Motion of Perigee (degrees/day)	-2.892	-2.890

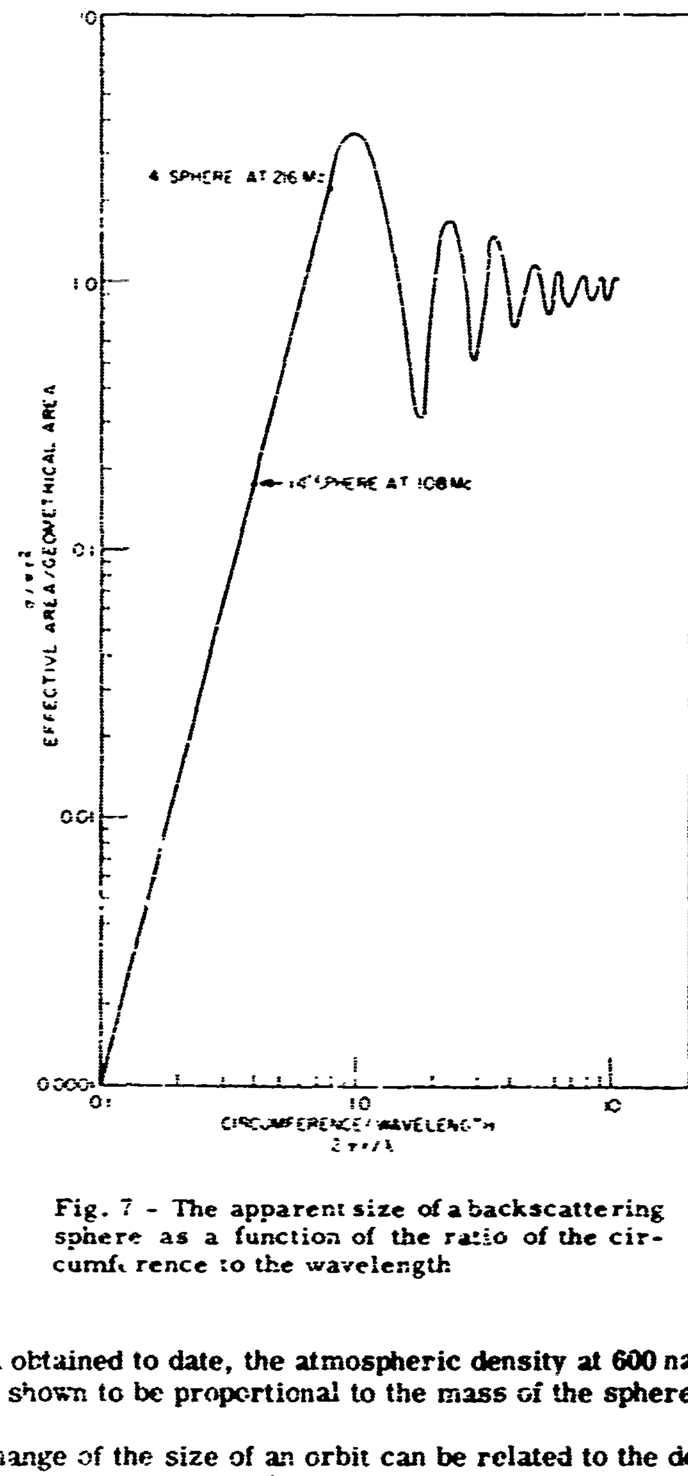

Fig. 7 - The apparent size of a backscattering sphere as a function of the ratio of the circumference to the wavelength

Using the data obtained to date, the atmospheric density at 600 naut mi has been evaluated, and the drag shown to be proportional to the mass of the sphere as follows:

The rate of change of the size of an orbit can be related to the density of the atmosphere for a nearly circular orbit by (6):

$$\frac{da}{dt} = -\frac{4\pi^2 a^2 N \rho C_D A}{M}$$

where

a = semimajor axis

ρ = density of the atmosphere

C_D = 2 for spheres

A = projected area of the sphere = 1.1 ft^2

M = mass of the light sphere = 2.2 lb

N = mean motion of satellite.

The values of a and N are given to eight decimal places in the five-card orbital element system now released by NAVSPASUR.

Inserting all conversion factors:

$$\frac{da}{dt} = 2.62(10)^{10}\rho$$

$$\rho = -\frac{da}{dt}\,\frac{10^{-10}}{2.62}.$$

The mean value of da/dt for 76 days is $1.98(10)^{-7}$ earth radii/day. The mean value of ρ is $7.54(10)^{-18}$ slugs/cu ft. This value agrees within 10 percent of the quiet-sun atmospheric density (6).

The value of da/dt for the 22-lb sphere was similarly calculated as $1.879(10)^{-8}$ earth radii per day. The rates of change were determined by least squares fit of the NAVSPASUR computed values of a. The ratio of the two decay rates is 10.5, which agrees well with the actual ratio of their masses of 10.

A longer period of observation should improve the results and may suggest further experimental checks on the orbital theory.

CONCLUSIONS

Two smooth metal spheres have been orbited which are ideal targets for the calibration of high-sensitivity microwave space-tracking and surveillance radars. They are useful in evaluating sensitivity changes in the U.S. Navy Space Surveillance System and will be more valuable in the future when system frequency is converted from 108 Mc to 216 Mc and its sensitivity increased. Fourteen-inch-diameter spheres are still too small, however, for omnidirectional scattering required for the absolute calibration of a multistatic system.

A preliminary analysis of the change in orbital elements of these satellites determined from the U.S. Navy Space Surveillance System indicates that the change in semimajor axis, and hence period, is proportional to the ballistic coefficients of the two spheres, indicating that residual air drag is the only observable force acting on the spheres on a long-time basis. The absolute atmospheric density, deduced from the decay in semimajor axis of the light sphere, indicates a value consistent with the "quiet-sun" model of the upper atmosphere (6).

RECOMMENDATIONS

It is recommended that a large sphere be orbited at the first possible opportunity. The preferred orbit is as follows:

Apogee 10,000 statute miles

Perigee 500 statute miles

Inclination 45 to 90 degrees

The sphere should be one meter in diameter or larger and should be constructed of heavy metal (or loaded) so that the orbital perturbations due to solar radiations are small. One hundred pounds, perhaps, would be a useful weight.

ACKNOWLEDGMENTS

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